Passive heat and moisture exchangers

By Alex Yartsev - 10/08/2018
Last updated 22/04/2021 - 20:07

This is a hygroscopic filter which replaces the normal warming, humidifying and filtering functions of the upper airways when these structures are bypassed during anaesthesia and intensive care. Much of the material presented here is derived from an excellent series of articles by A.R Wilkes, published in 2010.

Anatomy of the HME

Looking at the Google images result, every aerobic organism out there seems to have designed and manufactured a HME at some stage. Certainly, there are vast multitudes of them, and they come in all shapes and sizes. The basic features however remain the same.

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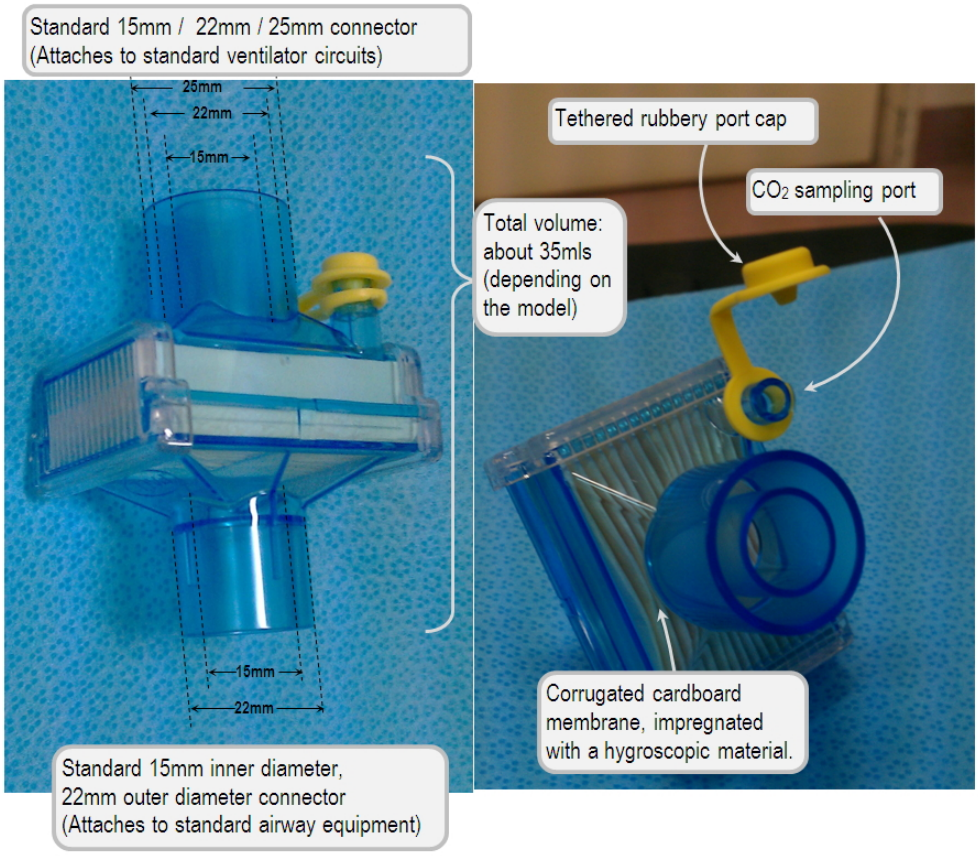

The HME at a basic level is a box with some scrunched up cardboard inside it. The casing is typically made of transparent plastic and is reasonably airtight. Certainly it does not seem to contribute to the circuit leaks.

Apparatus dead space

The volume of the HME varies, but tends to be as low as can be achieved, because the HME steals gas from your tidal volume. This is no issue for the huge seven-foot-tall Maori football player intubated for their elective arthroscopy, because their tidal volume is about 1000mle and they don't care about a little extra "apparatus dead space". However, if your tidal volume is substantially less, like if you're a tiny little grandma with ARDS, well - you need every millilitre of volume, you cant have 100ml of your 250ml V_T ventilating dead plastic.

Standard airway and ventilation circuit connectors

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The HME has connectors that are unambiguously one-sided. There is no way to hook it up to the ventilator the wrong way around. Only one end hooks up to ETT and ETT extensions; the other end hooks into T-pieces and ventilator circuit tubing.

The reason for this sort of arrangement is the fact that the crinkled cardboard filling has a polarity. That is to say, it presents a layer of material to the humid expired patient breath, which favours the deposition of water, and therefore heat. A porous plastic layer is sometimes present on the ventilator side, in order to act as a physical size barrier to the passage of bacteria and viruses. In the case of the filter available to me personally (i.e. the one I "borrowed" from an anaesthetic trolley) this is absent, and the filter itself is a ceramic-bonded pleated hydrophobic filter with properties which negate the need for such a plastic coating.

CO_2 sampling port

This is just your standard Luer-lock port for connecting a $EtCO_2$ sampling tube.

One can successfully forget about this accessory for the majority of one's HME experience. It only becomes a source of excitement when the little yellow rubbery port cap falls out of the hole accidentally, and the ventilator registers a rather large leak. Alarms will ring, the patient will desaturate, and all manner of comedy will unfold until somebody checks the little yellow rubbery port cap.

Capnometry with one of these filters is interesting. If the filter is too large, the capnometry trace will be altered, or it may disappear altogether. Not only that, but there is usually some difference between the pre-filter and post-filter CO_2 levels, which is confusing (which one is accurate?). A soggy old filter may become so thick and boggy that all the CO_2 is trapped in it, and the $EtCO_2$ trace becomes flat.

Filter material

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As there are literally hundreds and hundreds of HME designs, so there are hundreds and hundreds of filter materials, each proprietary, patented, their chemical properties shrouded in mystery. In the days gone by, these were reusable and made from temperature-resistant materials such as silver-coated copper wire gauze and glass wool.

Of course, it remains to be proven whether these monstrously over-engineered filter boxes are in any way an improvement on the glass cylinder of moistened blotting paper pellets used by Cole in his famous 1953 experiments, which was *"found to condition respiratory air as effectively as the highly vascular mucosa of the upper respiratory tract"*.

Anyway. HME filters can be categorised into two basic subtypes.

Electrostatic filters tend to collect water vapour by means of electrostatic attraction; because of this, the filter tends to be thinner, and therefore offers less resistance to flow.

Pleated filters tend to collect water vapour by exposing the gas to a large surface area. These tend to be thicker, fluffier, more foam-like, and they offer greater resistance to gas flow. They are sometimes called "hydrophobic" filters because the surface of the filter repels water. This might seem counterintuitive, but the repulsion of water does not mean resistance to the deposition of humidity - rather, it means the tiny droplets which form on this surface do not absorb into the filter material, but instead remain on the surface, where they can be exposed to gas flow.

Resistance to flow is measured in terms of pressure generated across the filter at a certain flow rate. Obviously, every filter and every HME shape is going to be different. As an example, the filter used in the diagrams is rated to have a resistance of 3.6 cmH_2O at a flow rate of 65L/min.

As the filter ages and becomes waterlogged, it becomes a greater obstruction to flow. Resistance to gas flow can double with a soggy filter.

Of course, the larger the filter, the greater the surface area presented for gas movement, and thus the less the resistance to gas flow. But… the greater the apparatus dead space. So, it's something of a trade-off.

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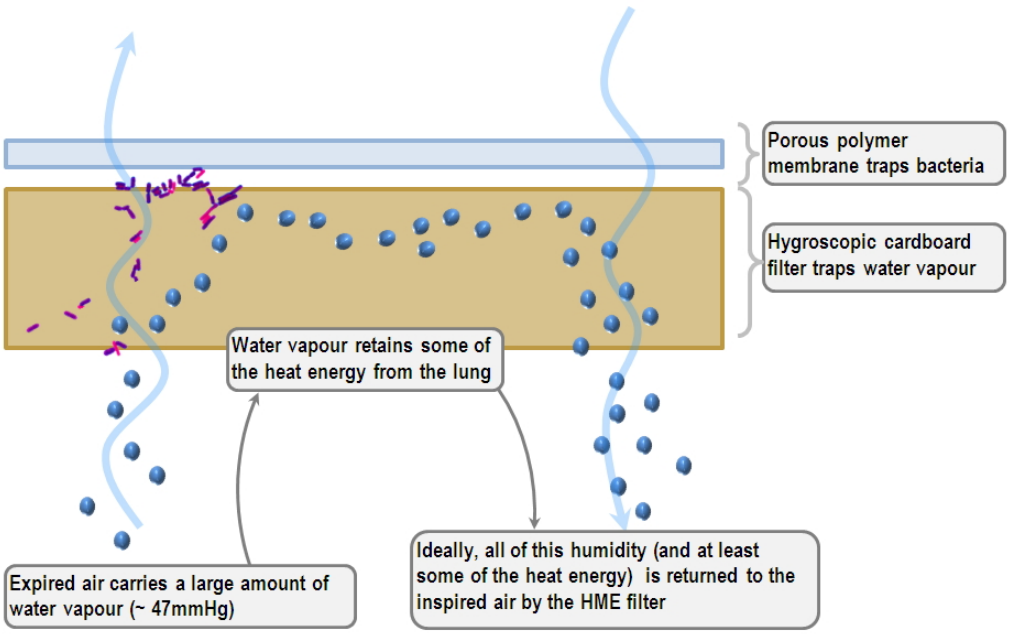
Details of function

During expiration, the HME picks up some of the moisture from the expired humid air.

These water droplets retain some of the heat from the gas which has carried them.

During inspiration, the incoming torrent of air collects these warm water droplets, and carries them as vapour into the lungs of your patient.



Normal humidity in the human airway

In 1953, an otolaryngologist assessed these variables, and found that some moistened pellets of blotting paper did as good a job at humidifying inspired air as a native human nose.

But that aside; turns out, the humidity in your oropharynx is very nearly 100% for a range of temperatures (that is to say, at 31° C there is about 31 g of water per every cubic meter of expired gas).

That range of temperatures tends to be pretty narrow, with a variation between

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There tends to be a so-called "isothermic boundary" just below the carina; this is the spot at which the inspired gas achieves a temperature of 37° and a 100% saturation, giving an absolute humidity of 47g/m^3

But- it turns out you don't actually need to have such optimal humidification at that level.

How much heat and humidity is enough?

The ISO had issued forth a mighty policy statement. That is a 19 page document, and I will spare the reader from its unearthly beauty by summarising that these days, the minimum amount of moisture delivered to the patient should be 33 g/m^3. So, you can safely cut down the humidity to 75% at 37°. This is based on data from the 1953 Williams review, where it was found that though the ideal humidity was 100%, one could get away with less without suffering any mucosal damage.

HME humidification is inadequate humidification.

Generally speaking, the HME only produces about 20 g/m^3 which is not enough for sustained protection of tracheal mucosa. It is, however, enough for anaesthetic procedures.

Consequences of inadequate humidification: inspissation of secretions

Well, a few things will go wrong if you allow improperly humidified or heated air to touch the fragile trachea, and the lungs beyond. Some of these were identified in a famous and often-quoted article by Williams (1996). He identified a progression of events in the respiratory system which takes place if there is a humidity deficit.

- First, no damage occurs for a while
- Then, the mucus thickens
- Mucociliary transport slows (cilia bogged down in the thickening mucus)

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- Cilia stop beating
- Mucosal damage occurs due to moisture loss and mucosal dehydration.
- Desquamation of epithelial cells and ulceration occurs.
- Mucus secretion continues, and gobs of dried mucus begin to form, occasionally dropping into the deeper bronchi to occlude them, causing atelectasis.

The "gob of mucus" statement is perhaps too kindergartenish to repeat in front of the gentlemen examiners, and the savvy fellowship candidate will instead describe the process of drying phlegm as "the inspissation of secretions".

What influences the effectiveness of the HME?

- **Its age.** Old HMEs (after, say, 24-48 hrs of use) become clogged with secretions, and no longer exchange moisture as effectively.
- **The tidal volume.** A large tidal volume is a HME's enemy. By the middle of a long inspiratory phase, the HME has become completely dehydrated, and all that remaining gas is completely dry. Small volumes result in better heat and moisture exchange

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Indications for use

- Humidification of inspired gas in short-term invasively ventilated patients, where equipment cost is a factor.

I can think of no other indication. One might mention something like "protection of the circuit from bacteria", or "prevention of VAP" but this is controversial.

Contraindications for use

- **Conditions that demand a tight control of apparatus dead space**, such as ARDS.
    - Obviously, when your total tidal volume is about 180ml, you

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to be wasting a lot of it on ventilating the

HME. Reducing the "apparatus dead space" is a very effective strategy to combat hypercapnea in ARDS.

- **Large volume of secretions or froth**
    - Firstly, these will clog up your HME, causing a resistance to airflow (and thus increasing the peak airway pressure)
    - Secondly, the amount of humidification provided by the HME is not going to be enough to help the secretion clearance - one really needs optimal humidification for nice, fluid, easily suctioned sputum.
    - Thirdly, the sputum-clogged HME can produce such a large amount of airflow resistance that the ventilator becomes fooled, and the circuit disconnection alarm fails to activate when the patient accidentally self-extubates.
- **Large minute volume** (over 10L/min)
    - The reason for this is related to increased moisture exchange from the secretions. It's a fairly simple physical principle - the more gas wafts over your mucosa, the more moisture it will carry with it. The amount of moisture removed in this way will exceed the capacity of the filter; the filter will basically dry out with each breath. A 1988 study first found this association.
- **Large air leak, eg. bronchopleural fistula**
    - With a constant air leak, gas is constantly flowing past the filter (and then through the bronchi, out of the bronchial perforation, into the pleural space, and then into the intercostal drain, and then out into the wall suction outlet.
- **Long term ventilation**
    - Firstly, these things only last 4 days, max (ideally you should switch them every 24hrs)
    - Secondly, if you are going to be ventilating somebody in the long term, their secretions will get thicker and thicker with the inadequate amount of humidification produced by the HME.
    - Being intubated they will depend on suctioning for secretion clearance, and suctioning will not be very easy with thick ns.

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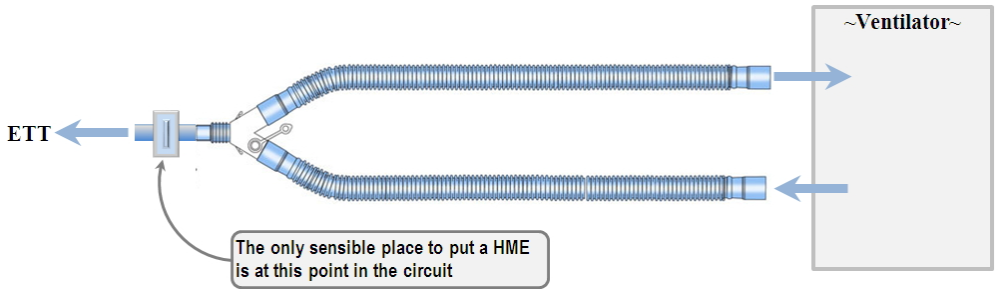
    - Thus, don't ventilate people with HMEs in the long term.
- **Frequent nebulised medications**
    - Clearly, if you are going to give nebs, you are going to give them *downstream from the HME.*
    - Having said that, I have seen people nebulising their salbutamol into the HME, and wondering why the bronchospasm is not responding.

Methods of use/insertion



There really is only one sensible place to put a HME, and that is closest to the patient, where the humidity is greatest. If you put it further and further away, the humidity in the expired gas will just "rain out" and precipitate itself on the surfaces of the ventilator tubing, where it pools, bubbling uselessly and triggering alarms.

Safety features

- Transparent outer casing, to better inspect the filter material
- Standardised connectors to ventilation equipment
- Antibacterial filter material in some models
- Small volume, to minimise apparatus dead space
- Single use item

Complications of use

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- The inspissation of secretions
- Difficulty aspirating thickened secretions
- The incrustation of endotracheal tubes with thick secretions, with increasing peak airway pressures
- Possibility of undetected circuit disconnection, or airway obstruction
- Colonisation of filter with respiratory pathogens (but this is again an unproven allegation)

Previous chapter: Active circuit humidification equipment

Next chapter: Methods of generating positive ventilator circuit pressure

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References

Drager have a nice brochure, spruiking the virtues of their HME systems.

However, the depicted item is the Pall Ultipor 25 Breathing System Filter.

Its all I had. Thank you to the theatre staff for kindly letting me break this piece of equipment.

he international standard for adequate humidifcation can be found here, at the ISO:

Respiratory tract humidifiers for medical use -- Particular requirements for respiratory humidification systems

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